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Shelf-Life Study of an Orange Juice–Milk Based Beverage after PEF and Thermal Processing

F. Sampedro, D.J. Geveke, X. Fan, D. Rodrigo, and Q.H. Zhang

ABSTRACT: The effect of thermal and pulsed electric field (PEF) processing on the shelf life of an orange juice–milk beverage (OJMB) was studied. The intensities of the treatments were selected to produce similar inactivation of pectin methyl esterase (PME), an enzyme responsible for the jellification and loss of fresh juice cloudiness. Physical properties (pH, °Brix, and color), microbial population, PME activity, and volatile compounds of the product were analyzed during a 4-wk storage at 8 to 10 °C. The pH was not affected by any treatment but decreased during the storage in the untreated sample. The °Brix values were decreased by the 2 treatments. The thermal and PEF treatments initially inactivated PME activity by 90%. During storage, the PME activity remained constant in the 2 treated samples and decreased slightly in the untreated sample. The reductions in bacterial as well as yeast and mold counts were similar after the 2 treatments (4.5 and 4.1 log CFU/mL for thermal against 4.5 and 5 log CFU/mL for PEF). Based on the initial bacterial counts of the control, it was estimated that the shelf lives of the OJMB treated with thermal and PEF processing stored at 8 to 10 °C were 2 and 2.5 wk, respectively. Differences were observed in the color parameters of the OJMB between the 2 treatments in comparison with the control, with a higher difference observed in the thermally processed samples. The relative concentration of volatile compounds was higher in OJMB processed by PEF treatment than that in the thermally processed sample. During storage, the loss of volatile compounds was lower in the PEF sample while thermal and control samples had a similar rate of loss. For an OJMB, treatment with PEF achieved the same degree of microbial and enzyme inactivation as the thermal treatment, but better preserved color and volatile compounds.

Keywords: juice, milk, pulsed electric field, shelf life, thermal processing

Introduction

High quantities of new minimally processed foods have appeared on the market in response to a growing demand for natural products that are perceived by consumers as healthier. Among them are beverages based on a mixture of fruit juices and milk fortified with vitamins, minerals, and fiber. These beverages are the most widely consumed functional foods (Pszczola 2005); however, there is little data related to quality and safety of these products.

These products need a cold chain for their storage and distribution. Many refrigerators in Europe are set at a temperature around 8 °C. This situation points to conducting the research on the shelf life of these products at more realistic conditions using temperatures higher than 4 °C. In addition, many studies on shelf life that compared different technologies (pulsed electric field [PEF], thermal processing, and high hydrostatic pressure [HHP]) applied different intensities (Jia and others 1999; Yeom and others 2000; Élez and others 2006; Rivas and others 2006; Aguilar and others 2007), which made the results not comparable. When comparing different technologies, it is very important to choose the right conditions to achieve similar inactivation of selected microorganism(s) or enzyme(s). In our unpublished study (Sampedra and others 2009), the conditions that obtained the same degree of pectin methyl esterase (PME) inactivation by thermal and PEF treatments were first developed.

PME is an important enzyme in orange juice-based products causing the cloud loss of juice or jellification of juice concentrates. Thermal pasteurization of juice is based on the PME inactivation level of >90% because its thermotolerance is higher than the majority of microorganisms found naturally in this type of product (Tribess and Tadini 2006). Severe conditions (90 °C, 1 min or 95 °C, 30 s) are necessary to inactivate orange PME (Cameron and others 1994; Do Amaral and others 2005). Normally, industry pasteurizes orange juice at 88 to 95 °C for 15 to 30 s (Irwe and Olson 1994). Unfortunately, these treatments can alter aroma, color, and other attributes of the fresh orange juice (Farnworth and others 2001; Lee and Coates 2003).

Several researchers have studied the shelf life of different foodstuffs after PEF and thermal treatments such as blended orange and carrot juice (Rivas and others 2006), apple juice and cider (Evrendilek and others 2000), cranberry juice and chocolate milk (Evrendilek and others 2000), tomato juice (Min and Zhang 2003; Min and others 2003b), and orange juice (Yeom and others 2000; Ayhan and others 2002; Min and others 2003a; Élez and others 2006); however, there are no studies comparing the effects of PEF and thermal treatments on the shelf life of a complex composition food such as a mixture of orange juice and milk.

The aim of this study was to perform a shelf-life study of an orange juice–milk based beverage (OJMB) after thermal and PEF treatments.

MS 20080379 Submitted 5/21/2008, Accepted 11/8/2008. *Author Sampedro is with Inst. of AgroChemistry and Food Technology, CSIC, P.O. Box 73, 46100 Burjassot, Valencia, Spain. Authors Geveke, Fan, and Zhang are with Eastern Regional Research Center, Agricultural Research Service, U.S. Dept. of Agriculture, 600 East Mermaid Lane, Wyndmoor, PA 19038, U.S.A. Author Rodrigo is with Nutrition and Bromatology Area, Faculty of Pharmacy, Univ. of Valencia, Vicent Andrés Estellés S/N, 46100, Burjassot, Valencia, Spain. Direct inquiries to author Fan (E-mail: xuetong.fan@ars.usda.gov).*

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Materials and Methods

Beverage preparation

Fresh Valencia var. oranges were purchased at a local supermarket. The oranges were squeezed using a juice extractor (Zumex 38, Zumex, S.A., Valencia, Spain) and the juice was filtered with sterile cheesecloth and stored at −40 °C until use. The OJMB contained the following ingredients: fresh orange juice (500 mL/L), commercial UHT skimmed milk (200 mL/L), 3 g/L high methoxyl citrus pectin (Unipectine AYD 250, Cargill, Minn., U.S.A.), sucrose (75 g/L), and deionized water (300 mL/L). Prior to mixing, solid ingredients were dissolved in water in the weight proportions as indicated previously. The OJMB was prepared just before use. The OJMB physicochemical characteristics were reported in a previous article (Sampedro and others 2007).

Thermal treatment

Thermal treatment conditions were chosen based on the results obtained in our unpublished study to obtain 90% of PME inactivation. The experiments were carried out in a plate and frame heat exchanger equipped with nominal 66 s hold-time tube (FT74X/HTST/UHT, Armfield Inc., Hampshire, U.K.). OJMB placed in a feeding tank was driven by a pump to the heat exchanger at 170 mL/min where it was rapidly heated to 85 °C. Then the product reached the holding tube where the treatment conditions (85 °C, 66 s) were maintained. After the treatment, the OJMB was immediately chilled with cold water (20 °C) in a cooler (FT61, Armfield Inc.), and it was packaged and stored until needed for analysis.

PEF treatment

PEF treatment conditions were chosen based on the results obtained in our unpublished study to obtain a 90% of PME inactivation. An OSU-4F bench-scale continuous unit (Ohio State Univ., Ohio, U.S.A.) was used to treat the food sample (Sampedro and others 2007). Six co-field chambers with a diameter of 0.23 cm and a gap distance of 0.29 cm between electrodes were connected in series. One cooling coil was connected before and after each pair of chambers and submerged in a circulating bath (model 1016S, Fisher Scientific, Pittsburgh, Pa., U.S.A.) to maintain the selected initial temperature (65 °C). The temperature was recorded by thermocouples (K type) at the entrance and exit of each pair of chambers. The entrance of the 1st treatment chamber can be considered as the initial temperature (65 °C) and the exit of the last treatment chamber as the final temperature (80 °C). The values were recorded with a data logger (Sper Scientific, Scottsdale, Ariz., U.S.A.). Pulse waveform, voltage, and current in the treatment chambers were monitored with a digital oscilloscope (TDS 210, Tektronix, Richardson, Tex., U.S.A.). The flow rate was set at 120 mL/min with a digital gear pump (Cole Parmer, Ill., U.S.A.). A bipolar square-wave of 2.5 μs was selected. Treatment time was set at 50 μs and the electric field at 30 kV/cm. The sample was immediately cooled in ice-water and it was packaged and stored until needed for analysis.

Packaging and storage

The treated product was packaged in clean, sterile twist-off glass (500-mL) jars inside a laminar flow hood. The closed jars were stored in a refrigerator at 8 to 10 °C in darkness. Quality analyses discussed in the following sections were carried out after 1, 2, 3, and 4 wk.

Analysis of headspace volatile compounds

Volatile compounds were extracted with a modification of the method described by Fan and Gates (2001) using a solid-phase microextraction (SPME) method. A 2-mL aliquot sample was transferred into 6 mL serum vial. The vial, sealed by a teflon-lined septum and a screw cap, was preheated at 60 °C for 2 min before a SPME fiber, coated with 100 μm of poly(dimethylsiloxane), was inserted into the headspace of the sample bottle. After 30 min incubation, the SPME fiber with adsorbed volatile compounds was inserted into the GC injection port at 250 °C and held there for 5 min to desorb volatile compounds. Volatile compounds were separated by a Hewlett-Packard 6890N/5973 GC-MSD (Agilent Technologies, Calif., U.S.A.) equipped with a DB-Wax trace analysis column (30 m × 0.32 mm i.d., 0.5-μm film thickness). The temperature of the GC was programmed from 60 to 96 °C at 8 °C/min, increased to 120 °C at 12 °C/min, then increased to 220 °C at 10 °C/min and held for 3 min at the final temperature. Helium was the carrier gas at a linear flow rate of 39 cm/s. Compounds were chemically identified by comparing spectra of the sample compounds with those contained in the Natl. Inst. of Standards and Technology library (NIST02). The relative amount of each compound was expressed as peak areas.

PME activity measurement

PME activity was determined by measuring the release of acid over time at pH 7 and 22 °C. The reaction mixture consisted of 1 mL of sample and 30 mL of 0.35% citrus pectin solution (Sigma, Mo., U.S.A.) containing 125 mM NaCl. During hydrolysis at 22 °C, pH was maintained at 7 by adding 10^{-4} N NaOH using an automatic pH-stat titrator (Titralab, Radiometer Analytical, SAS Inst., Cary, N.C., U.S.A.). After the first minute, the consumption of NaOH was recorded every 1 s for a 3-min reaction period. PME activity was expressed in units (U), defined as micromoles of acid produced per minute at pH 7 and 22 °C. The detection limit was established at 0.019 U/mL. Residual activity was expressed as the relation between the PME activity after the treatment (A) and the initial activity (A_0) expressed in units per milliliter.

Physical property measurements

The physical properties such as pH, °Brix, and visual inspection (phase separation) were measured at room temperature. An Orion 420A+ pH meter (Thermo Electron Corp., Beverly, Mass., U.S.A.) and hand refractometer (Leica, Buffalo, N.Y., U.S.A.) were used to determine the pH and °Brix, respectively. Color was measured with a colorimeter (MiniScan XE, Hunter Associates Lab., Reston, Va., U.S.A.) using a 27-mm measuring aperture. The colorimeter was calibrated using the standard white and black plates. D65/10° was the illuminant/viewing geometry. Triplicate measurements of L^*, a^*, and b^* were recorded for each sample. Product (75 mL) was placed into a 2.5-inch (diameter) glass measuring cup. The cup was then placed onto the 27-mm port for color measurement. A black cover over the cup was used. L^* is a measure of brightness/whiteness that ranges from 0 to 100 (white if $L^* = 100$, black if $L^* = 0$). A^* is an indicator of redness that varies from $-a^*$ to $+a^*$ ($-a^*$ = green, $+a^*$ = red). B^* is a measure of yellowness that varies from $-b^*$ to $+b^*$ ($-b^*$ = blue, $+b^*$ = yellow). Also, the total color differences (ΔE) between the control and treated sample was calculated by the equation proposed by Cserhalmi and others (2006):

$$\Delta E = \sqrt{(\Delta L)^2 + (\Delta a)^2 + (\Delta b)^2} \quad (1)$$

Depending on the value of ΔE, the color difference could be estimated such as not noticeable (0 to 0.5), slightly noticeable (0.5 to 1.5), noticeable (1.5 to 3), well visible (3 to 6), and great (6 to 12).

Microbiological assay

The microbial inactivation and growth were examined by diluting the samples in 0.1% (w/v) sterile peptone water and plating in tryptic soy agar (BD, Sparks, Md., U.S.A.) for bacterial counts and in acidified potato dextrose agar (BD) for yeast and mold counts every week for 4 wk. Plates were incubated at 37 °C for 48 h for bacteria and at 30 °C for 2 and 5 d for yeast and mold counts.

Statistical analysis

The statistical analysis was performed using the software Statgraphics® Centurión XV (Statistical Graphics Corp., Princeton, N.J., U.S.A.) applying a univariant analysis of variance (ANOVA) test with a significance level of 95% ($P = 0.05$). The effect of treatments was determined using the Tukey's test.

Results and Discussion

Effects of processing and storage on physical properties

The effect of thermal and PEF on the OJMB physical properties are shown in Table 1. There were no significant ($P > 0.05$) differences in the pH values after the different treatments. Many researchers have observed no variation in the pH value after different thermal and PEF treatments in different fruit and vegetable juices (Min and others 2003a, 2003b; Cserhalmi and others 2006; Élez and others 2006; Rivas and others 2006; Aguilar and others 2007). During the storage, pH value decreased in the untreated sample due to the growth of microorganisms that produced lactic acid (data not shown). The pH of the thermal and PEF processed samples decreased slightly in the last week of storage due to the increase in microbial population. Élez and others (2006) found a decrease in pH in the unprocessed sample from d 28 to 56 at 4 °C in orange juice. Yeom and others (2000) and Min and others (2003a) found no differences in the pH value of orange juice between PEF and thermal treated samples during a 112-d storage at 4 and 22 °C. Rivas and others (2006) found a decrease in pH value of a PEF (25 kV/cm, 280 μs) treated blended orange–carrot juice after 8.5-wk storage at 12 °C owing to microbiological spoilage.

The °Brix values decreased significantly ($P < 0.05$) after the different treatments. However, the differences between the mean values of the untreated and treated samples were less than 0.5, which was practically negligible. Cserhalmi and others (2006) and Rivas and others (2006) also observed a slight decrease in the °Brix values after PEF treatment in orange and blended orange–carrot juice, respectively. During the storage, the °Brix value decreased significantly ($P < 0.05$) in the untreated sample (data not shown). The growth of microorganisms could cause this phenomenon by fermentation of sugars. However, there were no significant ($P < 0.05$) differences between the thermal and PEF treated samples. Similar results were also found previously in orange and orange–carrot juice (Yeom and others 2000; Min and others 2003a; Rivas and others 2006).

Table 1 also shows the effect of different treatments on L^*, a^*, and b^* color parameters. There was a significant ($P < 0.05$) decrease in L^*, a^*, and b^* after the different treatments. The ΔE of samples was 2.70 after PEF treatment and 2.77 after thermal treatment with a noticeable color difference compared to controls. Cserhalmi and others (2006) found no differences between the untreated and PEF treated samples in orange juice ($\Delta E = 0.47$). L^* values were maintained during the first 3 wk of storage and decreased in the 4th week in the PEF and thermal treatment with no significant ($P > 0.05$) difference in the untreated sample (Figure 1).

There were no significant change in the a^* values in any sample during the first 3 wk. However, an increase occurred in the 4th week in the untreated and PEF sample while no change in the thermal sample was observed (Figure 1). The b^* values decreased during storage in untreated and PEF samples but increased after thermal treatment (Figure 1). Rivas and others (2006) found no differences in the luminosity and saturation after thermal and PEF treatments in an orange–carrot juice but an increase in the hue angle was

Table 1—Effect of thermal and PEF processing on different parameters of an orange juice–milk beverage.

Parameters	Untreated	Thermal	PEF
pH	4.31 ± 0.02[Aa]	4.39 ± 0.01[a]	4.36 ± 0.01[a]
Bacteria (log CFU/mL)	5.99 ± 0.02[a]	1.42 ± 0.08[b]	0.92 ± 0.25[b]
Yeast and mold (log CFU/mL)	5.43 ± 0.03[a]	0.92 ± 0.11[b]	0.43 ± 0.09[b]
°Brix	15.07 ± 0.06[a]	14.83 ± 0.06[b]	14.65 ± 0.07[c]
PME (U/mL)	0.362 ± 0.03[a]	0.039 ± 0.001[b]	0.035 ± 0.002[b]
L^*	56.30 ± 0.04[a]	55.68 ± 0.01[b]	55.92 ± 0.05[c]
a^*	1.85 ± 0.05[a]	−0.37 ± 0.02[b]	0.81 ± 0.06[c]
b^*	38.82 ± 0.10[a]	22.08 ± 0.02[b]	25.19 ± 0.06[c]

[A]Numbers are means of 3 replicates followed by standard deviation. Means with the same letter are not significantly different ($P > 0.05$).

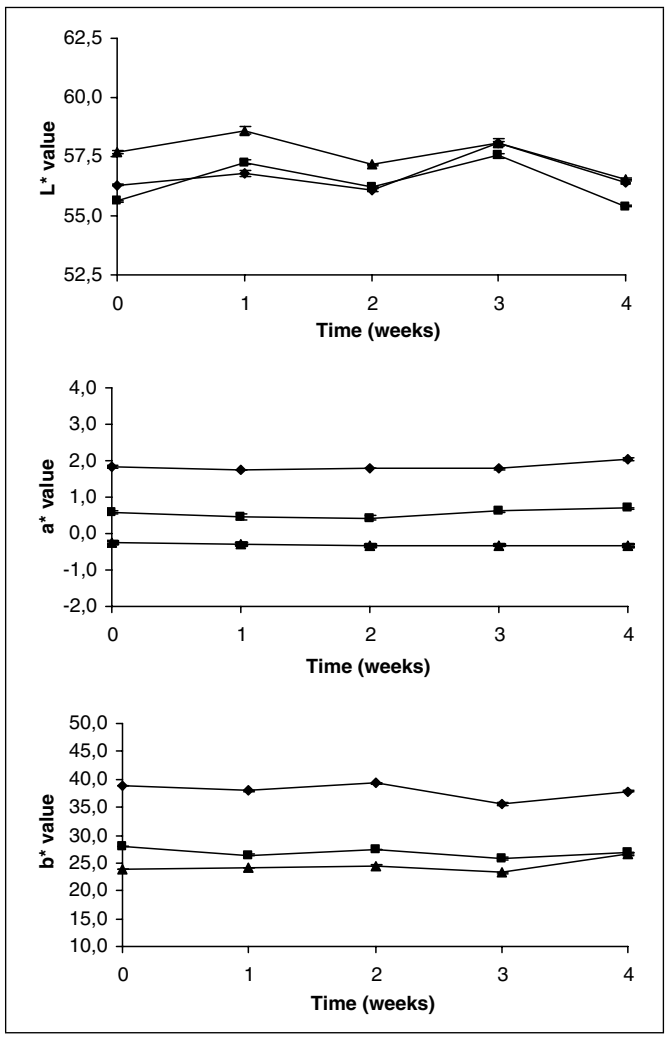

Figure 1—Changes in color parameters during storage of untreated control sample (♦), and thermally (▲) and (■) PEF processed samples at 8 to 10 °C.

observed after each treatment. During storage, the researchers did not observe any change in color parameters in the PEF treated sample but did in those of thermal treated samples. Min and others (2003a) found higher L^* and hue angle values during the storage for 196 d at 4 °C of PEF-treated samples than that of thermally treated samples. Ayhan and others (2002) found that the PEF-treated sample had higher L^* and b^* values and lower a^* value than fresh orange juice (brighter and more yellowish).

Effects of processing and storage on microbial flora

The effect of thermal and PEF processing on bacterial counts and yeast and mold counts in the OJMB are also shown in Table 1. Bacterial counts and yeast and mold counts of the untreated sample were 5.99 and 5.43 log CFU/mL, respectively. Bacterial counts were reduced by 4.57 and 5.07 logs after thermal and PEF processing, respectively. Yeast and mold counts were reduced by 4.1 logs by the thermal treatment and 5 logs by the PEF treatment. There were no significant ($P > 0.05$) differences in the microbial reduction between the 2 technologies. Min and others (2003a, 2003b) achieved a 6 logs inactivation of endogenous bacteria in tomato and orange juices after the thermal (90 °C, 90 s) and PEF treatments (40 kV/cm, 57 μs and 45 °C).

During storage, there was an increase of 4 to 6 log CFU/mL in bacterial counts as well as yeast and mold count in the untreated sample (Figure 2). The increase in the microbial populations was higher than in previous shelf-life studies likely due to elevated storage temperature (8 to 10 °C) used in the present study. The increases in both bacterial counts and yeast and mold counts of PEF and thermally processed samples during storage were about 6 logs (Figure 2). The shelf life of the treated samples was established taking into account initial microbial populations of the fresh untreated sample. On this basis, the microbial populations of samples treated with thermal processing exceeded the initial count of untreated sample after 2 wk storage while it took 2.5 wk for the PEF treated sample to reach the microbial populations of fresh sample. Therefore, the shelf lives were 2 and 2.5 wk at 8 to 10 °C for the thermally and PEF processed samples, respectively. Therefore, the PEF sample had a slightly higher shelf life than the thermal sample.

Different researchers have obtained quite long shelf lives of juices after different PEF treatments (Jia and others 1999; Yeom and others 2000; Élez and others 2006; Rivas and others 2006). Min and others (2003b) found increases of 3 logs in bacteria counts and 4 log in yeast and mold counts of PEF processed tomato juice occurred during 112 d at 4 °C. They argued that the increase of bacterial counts in the PEF-treated sample could be due to the relatively low inactivation of ascospores.

Effects of processing and storage on PME activity

The effect of thermal and PEF processing on PME activity is shown in Table 1. PME activity was inactivated by 89.4% and 90.1% after the thermal and PEF treatments, respectively, with no significant ($P > 0.05$) difference between the 2 technologies. Different researchers have also obtained a high degree of PME inactivation after PEF treatment. Élez and others (2006) achieved 100% and 81.6% inactivation after thermal (90 °C, 1 min) and PEF (35 kV/cm, 1000 μs, 40 °C) processing, respectively. Rivas and others (2006) found 75.6% and 81% inactivation after PEF treatment (25 kV/cm, 60 °C, 280 and 330 μs, respectively) and 98% inactivation after thermal treatment (98 °C, 21 s). Yeom and others (2000) found an inactivation of 88% after PEF treatment (35 kV/cm, 59 μs, 70 °C) and 98% after thermal treatment (94.6 °C for 30 s) and there was no

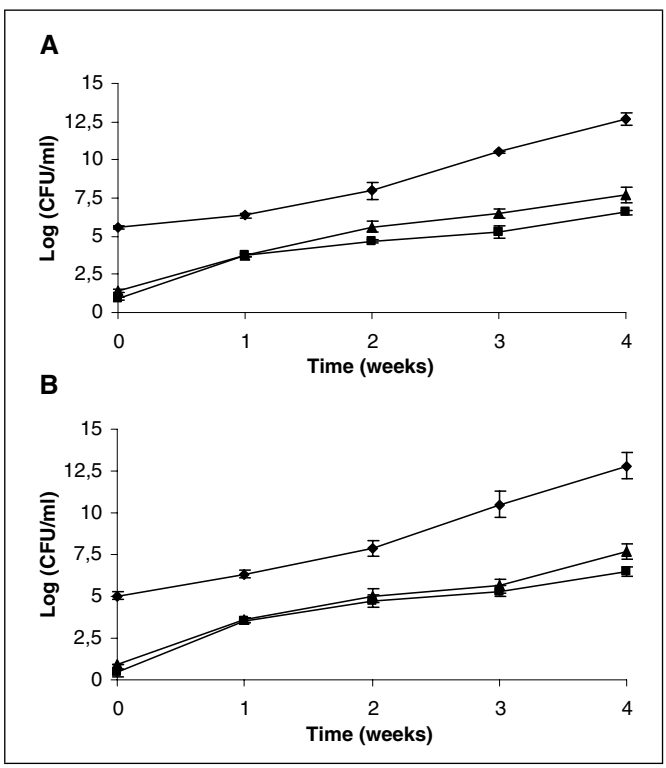

Figure 2—Growth of bacteria (A) and yeast and mold counts (B) during storage of untreated control sample (♦), and thermally (▲) and (■) PEF processed samples at 8 to 10 °C.

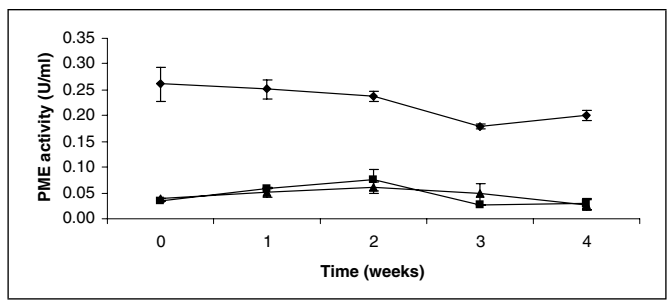

Figure 3—Change in PME activity during storage of untreated control sample (♦), and thermally (▲) and (■) PEF processed samples at 8 to 10 °C.

Table 2—Effect of thermal and PEF processing on volatile compounds content of an orange juice–milk beverage.

Compound	Retention time (min)	Loss (%) PEF	Loss (%) Thermal
α-Pinene	2.90	9.11 ± 2.61[Aa]	36.30 ± 0.28[b]
β-Pinene	3.71	4.66 ± 1.98[a]	44.14 ± 1.15[b]
β-Phellandrene	3.87	46.18 ± 0.25[a]	79.32 ± 9.02[b]
β-Myrcene	4.30	−25.76 ± 8.14[a]	31.74 ± 7.74[b]
Limonene	4.96	−5.68 ± 6.42[a]	8.26 ± 4.60[b]
α-Phellandrene	5.08	3.86 ± 5.50[a]	62.88 ± 0.86[b]
3-Carene	5.44	−23.01 ± 13.67[a]	40.91 ± 4.94[b]
4-Carene	5.95	−108.94 ± 2.20[a]	7.80 ± 13.12[b]
Nonanal	7.27	18.54 ± 7.67[a]	31.11 ± 5.80[a]
Ethyl octanoate	7.73	−26.39 ± 18.36[a]	−161.97 ± 22.85[b]
Decanal	8.55	11.80 ± 9.12[a]	28.99 ± 2.01[b]
Caryophyllene	10.69	35.93 ± 1.54[a]	39.52 ± 1.79[a]
Dodecanal	10.96	14.42 ± 1.85[a]	16.64 ± 7.96[a]
Valencene	11.23	21.77 ± 1.23[a]	27.74 ± 3.93[b]
Average loss (%)		−1.68	20.95

[A]Numbers are means of 3 replicates followed by standard deviation. Means with the same letter are not significantly different ($P > 0.05$). Positive numbers represent losses in the amounts of volatile compounds after processing while negative numbers represent gains.

activation after 112 d at 4 and 22 °C. The differences in the degree of PME inactivation achieved could be due to the orange variety, harvest season, treatment intensity, or type of food used in the study. All of these studies applied different treatment intensities for thermal and PEF processing obtaining different degrees of PME inactivation, thus making it difficult to compare the 2 technologies.

During storage, there was a significant ($P > 0.05$) decrease in the PME activity after the 3rd week in the untreated sample (Figure 3). Élez and others (2006) also found a decrease in PME activity of the untreated sample during storage. A phase separation was observed after a 2-wk storage in the untreated sample indicating the destabilization effects of the PME activity. The heights of serum (top) phase were 2 and 6.5 cm after 2 and 4 wk storage, respectively, for the nontreated samples. In the treated samples, there were no activation of the enzyme during the storage ($P < 0.05$) and there was no phase separation. In the thermal sample, a slight precipitation was observed at the bottom, maybe due to the casein precipitation. Several researchers have also observed no PME activation during storage after PEF treatment (Élez and others 2006; Rivas and others 2006). This fact demonstrates that PEF treatment in combination with heat (65 to 80 °C) can achieve irreversible inactivation of PME and a 90% PME reduction is enough to guarantee the stability of the product stored under refrigeration conditions.

Effect of processing and storage on volatile compounds content

The effect of thermal and PEF processing on the relative volatile compounds concentration in the OJMB is presented in Table 2. There were no differences in the amounts of nonanal, caryophyllene, and dodecanal after PEF and thermal treatments ($P > 0.05$).

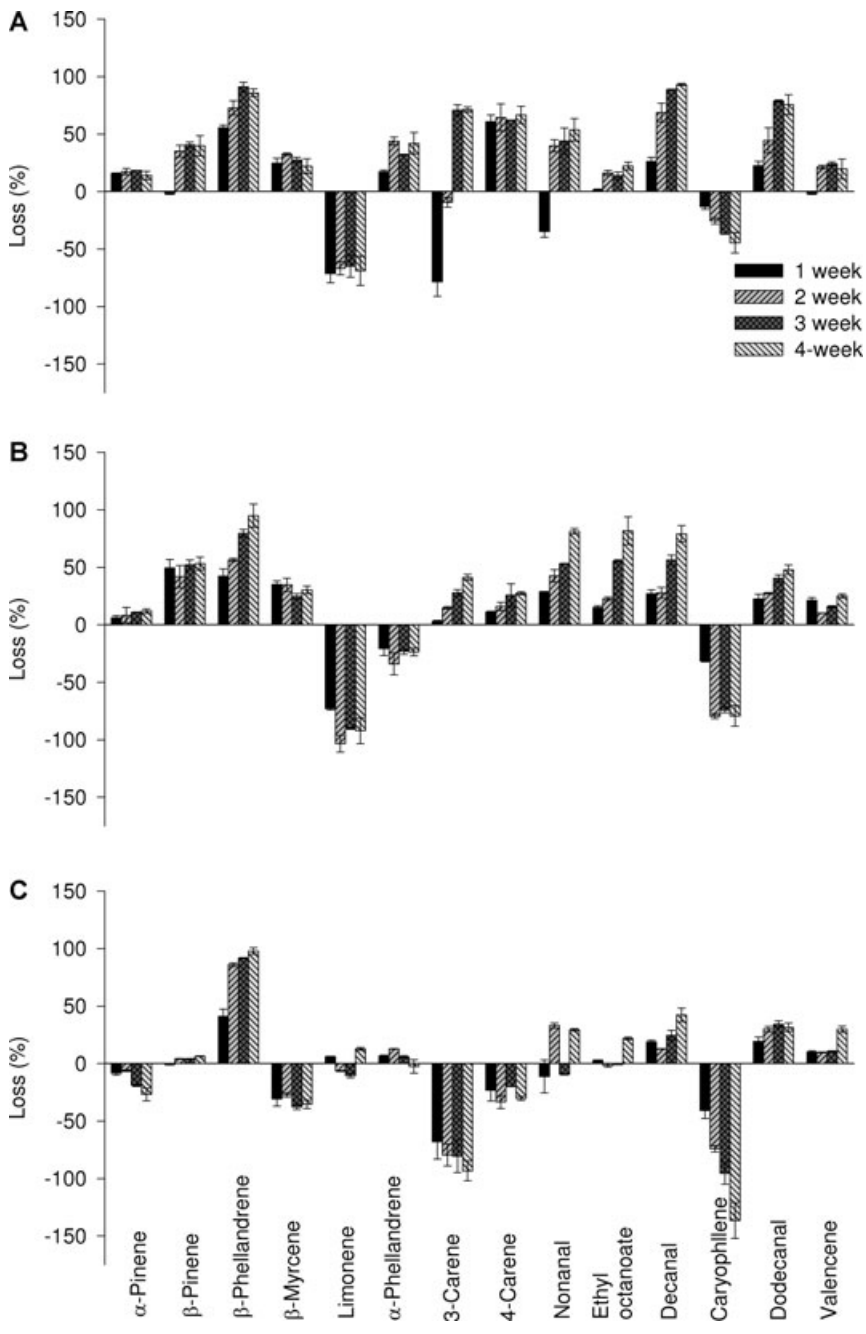

Figure 4 — Change of volatile compounds content during storage of untreated control sample (A), and thermally (B) and PEF (C) processed samples at 8 to 10 °C.

Changes of other volatile compounds were significantly less after PEF processing (−1.7%) compared with thermal processing (20.9%). Several researchers have also observed less volatile compounds loss after PEF treatment. Cserhalmi and others (2006) found no loss of volatile compounds content in an orange juice after PEF treatment (28 kV/cm, 100 μs), whereas Jia and others (1999) and Aguilar and others (2007) found less loss of volatile compounds after PEF than thermal treatment in orange and apple juices, respectively. They contended that the sensitivity of the volatile compounds to the PEF and thermal treatments depends on molecular weights and boiling points with the lower ones more easily lost during the treatments. However, in the previous studies, PEF treatment achieved less microbial inactivation than did the thermal treatment so the results were not comparable.

The compounds most sensitive to the thermal treatment were β-phellandrene and α-phellandrene, whereas limonene, 4-carene, and ethyl octanoate were the least sensitive to heat. On the other hand, β-phellandrene and caryophyllene were most sensitive to the PEF treatment.

The content of β-myrcene, limonene, 3-carene, 4-carene, and ethyl octanoate increased following PEF processing. Different theories could explain this phenomenon. Min and Zhang (2003) found that PEF sample had a lower particle size distribution and consequently, an increase in the release of the volatile compounds. Ayhan and others (2002) found an increase in the content of different volatile compounds (limonene, myrcene, valencene, and α-pinene) after PEF treatment (35 kV/cm, 59 μs) in orange juice. They reasoned that these compounds were found in higher concentration in the pulp and could be released after the PEF treatment into the aqueous phase.

During storage all compounds in the untreated sample decreased in the relative amounts of volatile compounds content except α-pinene, β-myrcene, 4-carene, limonene, and caryophyllene (Figure 4A). The average loss was 34.2%. The compounds that were lost to a higher extent were decanal and β-phellandrene. The content of volatile compounds in the thermal sample decreased during the storage except α-pinene, β-myrcene, α-phellandrene, limonene, caryophyllene, and valencene (Figure 4B). The average loss was 27.1%. β-Phellandrene, nonanal, ethyl octanoate, and decanal were lost most during the storage. Regarding the PEF sample, the average loss was 3.7% (Figure 4C). Compounds that increased their content during the storage of PEF samples were α-pinene, β-myrcene, α-phellandrene, 3-carene, 4-carene, and caryophyllene, whereas the content of decanal and β-phellandrene decreased. It seemed that during the storage some compounds could be also released from the pulp. Different researchers observed a slightly better preservation of volatile compounds in different fruit juices (orange and apple juice) after PEF treatment (Yeom and others 2000; Ayhan and others 2002; Min and Zhang 2003; Min and others 2003a). The storage temperature seemed to influence to a great extent the acceleration of the loss of volatile compounds content.

Conclusions

Both thermal and PEF processing achieved the same degree of enzyme and microbial inactivation of OJMB. Decreases in L^*, a^*, and b^* values were observed after thermal and PEF processing. During the shelf life of the OJMB at 8 to 10 °C, the untreated sample spoiled after 1 wk, whereas the PEF and thermally processed samples remained stable during the entire 4-wk storage period. Furthermore, slight decreases in pH, °Brix, and PME values occurred in the untreated sample during storage while a slight increase in the PME and no change in pH and °Brix values was observed in PEF and thermally processed samples. In addition, bacterial and yeast and mold counts increased by 4 to 6 logs in the untreated sample and approximately 6 logs in thermally and PEF processed samples during the 4-wk storage. Decreases in the concentration of volatile compounds also occurred in all samples, although the decrease in PEF processed sample was smaller. The results showed that, when achieving the same microbial and enzyme inactivation, the PEF processed sample had a slightly longer shelf life with better quality than the thermal processed sample.

Acknowledgments

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